# THE DISTRIBUTION OF TOTAL NITROGEN IN THE LEAVES AND THE BERRIES OF *COFFEA ARABICA* L. DURING THE FRUITING SEASON

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# INTRODUCTION

Nitrogen is a vitally important plant nutrient, the supply of which can be controlled by man. In coffee plants, the reduction of nitrate to ammonium, the form entering the biosynthetic pathway, is believed to take place predominately in the leaves (16, 59).

The fruits of coffee are such a powerful, dry matter sink that a continuous supply of nutrients in the fruiting season is essential (48). Nitrogen is one of the mobile elements that provide the need of growing terminals and developing fruit. The supply of this element to the coffee tree heavily depends on the availability of soil moisture (53). The timing of nitrogen fertilizer and the right dosage for a given tree was the goal of this study. During the experimental period, the critical level of nitrogen in the coffee plants under various seasons was also studied.

# REVIEW OF LITERATURE

Coffea arabica L., a species of the Rubiaceae family, is an upland crop growing as an understory in the forests of Southwestern Ethiopia. Over 90 percent of the world's production comes from arabica coffee.

Arabica coffee seems to have a wide range of adaptation away from its native home. Its native land, an ideal region for coffee*, has an elevation of about 1800 m with a moderately warm, wet summer and a cool, dry winter, the night temperature dropping to as low as 5°C in December. However, coffee has become acclimatized to elevations as low as 450 m in Kona, Hawaii (5). In Ethiopia, in general, the wild coffee forest extends from 6°N to 9°N and receives about 1900 mm of rainfall annually. This rainfall is well distributed throughout the year except for two to three months right after harvest (December-March) when it is dry, and has an average temperature range of 16-24°C (47). Ideal conditions noted in other countries fall in this range with few exceptions (5, 25, 31).

Little work has been done in the nutrition of coffee. Most growers believe that fertilizer applications boost yields. Nevertheless, the recommended annual N fertilizer rate ranges from as low as 50 kg/ha in Kenya, to as high as 1680 kg/ha in

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*Unless specified, coffee refers to Coffea arabica L.

Kona, Hawaii (47). Of all the nutrient elements, the relationship between coffee yield and the nitrogen fertilization is the most studied area in coffee nitrition.

Coffee is one of the most difficult crops to sample for diagnostic purposes (52, 56). For a general fertilizer recommendation, it is suggested that investigations be done on each location under prevailing variables.

Nitrate-N is the most predominant form absorbed by coffee roots (59). It is also stored in this form in leaves and wood when it is in excess amount. At times of scarcity, nutrients are mobilized to the fruits when fruit development is at a maximum (12, 15). This is particularly true with nitrogen as heavy bearing trees had shown a die-back which was corrected by the application of nitrogenous and other fertilizers (41). Establishment of critical nitrogen levels in the coffee plants is of paramount help in determining the right timing for the application of this nutrient.

## Ecology

Coffea arabica is a species that originated in the tropical rain forest. In this region, where coffee is at its best, the elevation ranges from 1300 m to 2000 m and the annual rainfall from 1200 mm to 2000 mm (37, 47) with distinct dry and wet seasons. The following species are in abundance as natural shade trees:

Albizia spp., Milletia feruginea, Croton macrostachys, Syzyium guineense, Sesbania spp., etc. (47).

As noted above, the coffee plant has shown remarkable adaptations to wide ranges of environmental conditions either in its native home or elsewhere. For instance, it is said that coffee can be grown with annual rainfall ranging from 762 mm to well over 2540 mm but the optimum amount ranges from 1500-2300 mm. In low rainfall areas such as the Yemen, it may be irrigated (47). Investigators on the relationship between annual rainfall and coffee production have differing views (57). However, a study of 36 years rainfall data in Kona has revealed that variability in annual coffee production may be ascribed to fluctuations in the February to June rainfall occurring during the year in which the fruiting wood was produced (24).

In most countries the elevational zonation closely corresponds to a mean annual temperature between 17° and 23°C, a temperature range which can be considered as optimum for arabian coffee (43). In addition to its key influence in the initiation and anthesis of flowers, temperature plays a vital role in the absorption and translocation of nutrients (28). Both extremes have retarding effects in ion uptake except on potassium which seems to have an increased absorption at lower than normal temperatures. Leaf nitrogen content was 2.55 and 2.39 percent at 13° and 38°C, respectively. The range varied from 3.57 to 4.08 percent with

a temperature range of 18°-28°C while N content of plants grown outdoors was 3.23 percent (28).

Most of the coffee in Kona is grown on soils of two great soil groups and rockland--the Kapoho family of the humic Latosol Group and the Kealakekua family of the Hydrol Latosol Group (55). These soils are porous, friable, and possess a well aggregated soil structure, good internal drainage, and good percolation. They are derived from thin layers of volcanic ash overlapping geologically recent lava flows (25). The pH runs from 5.0 - 6.5 with relatively high content of organic matter ranging from 8 - 15 percent, a rapid decomposition of the organic matter and rapid nitrification in the soil (25, 55). In Kenya it has been reported that with a heavy rain at the beginning of the wet season, soil nitrate-N levels tend to decrease rapidly, partly because of leaching losses and partly because of uptake by the crop. Short rainfall conditions encourage slight nitrate build up. Due to the rapid loss of nitrogen from the soil with heavy rain, frequent application of this element is commonly practiced in both Kenya and Kona (51).

## The Role of Nitrogen Fertilizer in Coffee Yield

Although coffee grows in most of the tropical countries around the globe, only a few countries have conducted elaborate research on the nutrition of this crop. In all of the coffee producing countries the search for the right amount of fertilizer

and the right time to apply is continued. The results in some countries have given some idea for those areas but could not be duplicated in other areas.

The coffee tree is very responsive to the levels of applied nitrogen and potassium among the major mineral nutrients. It was reported that a mature tree took up 100 gm of nitrogen per annum of which some was removed by the developing fruit while the bulk was returned to the soil by leaves and prunings. The uptake of potassium was similarly high as compared to other mineral elements. The role of nitrogen in the coffee tree cannot be overemphasized (15). In one study, plants grown in the absence of nitrogen performed least in growth and yield. The minus nitrogen plants grown on sand culture had the lowest leaf nitrogen with higher concentrations found in the young leaves than the old ones (19). Investigations in various countries have shown that nitrate-nitrogen is the predominant form found in coffee soils (6, 25, 51).

## Forms of Nitrogen Absorbed by the Coffee Tree

There is an upward movement of nitrate in soils which results in an accumulation of this ion in the first 15 cm of the soil, particularly in the dry season. Under dry conditions the trees could not absorb this nitrogen but, shortly after the onset of rains, the coffee plants absorb the available nitrogen rapidly showing a sharp increase in leaf-N (6, 51). In Kona the concentration of soil nitrate was found to vary inversely with the

rainfall. Nitrogen fertilized plots had higher nitrate-N concentration than the check but, in the wet season, an increased absorption of nitrogen by bearing trees and increased leaching contributed to lower nitrate and ammonium-N concentration in the treated plot than was found in the check. Although nitrate-N is the bulk of the nitrogen absorbed, trees at bearing age also require ammonium-N. When the trees reach bearing age the nitrate reduction capacity of the roots decreases substantially and the plants suffer from acute ammonium-N deficiency (25).

Unlike other tree crops, nitrate-N is the predominant form found in the roots and xylem sap of coffee trees (15, 62). In a study in Kenya the leaves, which represented only 31 percent of the dry weight of the tree, contained the largest percentage of absorbed nitrogen (14).

## The Effect of Season on N Concentration in the Tree

Nitrogen concentration in different parts of the tree is subject to a number of variables. The most important of these are: the physiological conditions of the tree and changes in seasonal patterns. Nitrate uptake was shown to occur at higher rates during short periods prior to anthesis, at the beginning of resumption of vegetative growth, and as fruits begin to ripen. Its intake diminished at flowering and after harvest. Ammonium-N did not follow this pattern (17).

An optimal level of leaf-N in one area could not satisfactorily

serve as a guide for a different area, or for that area in a different season. Bonnet (11) found that high yielding trees receiving 0.45 kg per tree of 5-10-10 fertilizer gave an average of 2.79 percent leaf-N in the fruit development period (summer) and 2.54 percent just before bloom (winter). A low yielding group gave 2.91 percent leaf-N in the summer and 2.52 percent in winter. Similar results which coincided with a low moisture period were found by other workers (53).

Leaf-N concentration for irrigated versus non-irrigated fields receiving no nitrogen fertilizer were about the same. Higher levels of nitrogen fertilizer in irrigated fields, however, gave an increase in leaf-N (1.89 - 2.1 percent) as well as in yield (53). In Colombia, trees fertilized with nitrogen showed significant increase in leaf-N only in April indicating the importance of period of leaf sampling (33).

The carbohydrate is an important factor in influencing nutrient concentration of the tree. A number of investigators found that floral differentiation, crop development and ultimate yield were associated with the levels of starch in the tree (23, 45, 49). Flower development and normal flowering were found to be associated with (1) the number of leaves on the branch, (2) the starch index of the wood, and the physiological condition of the tree (12, 30, 34). The starch value gradually declined during crop development and rose again after crop maturity (23, 45). This high assimilate

demand enhanced nitrate uptake during crop development. Although the uptake of nitrate and potassium were antagonistic, higher uptake of nitrate was recorded during fruit development. The absorbed nitrates were also metabolized rapidly by the fruits (13, 14, 15, 17). Deblossomed trees exhibited higher concentration of leaf-N when compared to fruiting trees.

Leaf Sampling

Leaf analysis is one of the diagnostic tools in the determinations of the nutrient requirements of many orchard trees. It has been used widely to obtain: (a) the nutritional status of the plant through the determination of the normal and abnormal levels of the minerals of the leaf, this being used as a guide for the correction of soil fertility, (b) to study the effect of fertilizer application, (c) to know the fertility of soils on which coffee is grown and (d) to determine the adequate fertilizer formula (33).

The choice of leaf pair for sampling varies from one place to another. In Brazil the use of the third or fourth leaf pair from the tip of a lateral branch had been recommended (36, 38). After a comprehensive review of the literature, Carvajal (16), concluded that the third to eighth pairs are most sensitive for NPK and starch levels. The third and fourth pairs of leaves are also used in East Africa (52, 53). Due to the variability of results with changes in environmental conditions and the decline in total N with age, study within a given locality and the use of young, fully

grown leaves were highly recommended (65).

Light intensity has tremendous impact on coffee leaf-N. Plants with heavy shade exhibited a higher concentration of total- and nitrate-N, but had low dry matter, soluble sugar and starch (59). Under full light intensity there was an increased differentiation of tissues resulting in a high number of nodes and reproductive organs, but growth was little affected. The trees in full light receiving nitrogen application had increased internode growth and fully grown leaves ultimately resulting in significant yield increase (41, 42).

The time of application of the fertilizer is also an important factor in the correlation of leaf-N with coffee yield. In Kenya the application of 50 to 100 kg of N per hectare was found to be optimum with the higher rates split into two applications (50). Recent studies have revealed that several applications of complete fertilizer over nitrogen alone was preferred (35). In Guatemala, nitrogen fertilizer applications were recommended at the beginning and the middle of the heavy rainy season (44). In Puerto Rico, two split applications of 224 - 84 - 448 kg/ha of N, P, and K on trees with no shade gave a significantly high yield over one-half this dose (44). A 336 kg/ha each of N and $K_2O$ also gave a significantly high yield when compared to lower rates and corresponded with a leaf-N of 2.50 to 3.00 percent (54). In Cameroon, heavy demand of N in Robusta coffee was seen between April and May and

November and December (7). In Kona, high rates of nitrogen fertilizer in combination with high rates of potash gave high yield (4, 22, 25).

Nitrogen Concentration of the Berries

The nitrogen content of the coffee berry increases steadily throughout the period of growth and keeps pace with the increase in dry matter (3). Wormer (67) reported that a period of rapid growth follows 6 - 8 weeks after flowering and ends when the berry is about 17 weeks old. Thereafter, a small loss of fresh weight occurs while the dry weight remains constant for about two weeks. At this stage the beans have attained their final size but the dry matter can be as low as 9 percent. Until the time of beginning of berry ripening the fresh weight of the berry increases regularly. In this period, dry weight is laid down mainly in the beans which attain their final dry weight when the berry is still green. Between 23 and 32 weeks after flowering, most of the newly formed dry matter goes into the beans while afterwards all of it goes into the pulp. Some investigators found that nitrogen concentration of the berries increases as fruit maturity progresses (3, 27) but Cannell (15) found that the percentage of nitrogen in fruits, as well as that of most other mineral elements, decreased as they developed. Sixteen percent of the total organic-N absorbed by the plant was found in the fruit.

The performance of different sources of nitrogen fertilizers was tested on coffee trees in Puerto Rico. Sodium nitrate seemed to be least effective. It also caused a consequent rise in soil pH and leaf-$Na^+$. Ammonium sulfate resulted in high leaf Mn while ammonium sulfate, potassium nitrate, ammonium nitrate, and ammonium nitrate-lime gave about the same average yield of marketable coffee. Urea was preferred to ammonium sulfate as the latter decreased soil pH thus inducing Mn toxicity unless proper liming was done (1). Ammonium nitrate and also ammonium sulfate were found to induce Fe and Mg deficiency in coffee leaves. In addition, they have slightly increased the concentration of leaf and soil Zn and Al. The use of urea and basic slag or complete fertilizer as the source of N was suggested as preference (64).

Investigations on the effect of nitrogen fertilizer on other tree crops reveals tremendous influence on growth and yield. In fig, nitrogen fertilizer applied throughout the dormant season gave initially high leaf-N which gradually decreased as season and fruit maturity progressed (46). Storage nitrogen of the tree is important in flowering and fruiting of peach. Nitrogen reserve was dependent on the supply of nitrogen fertilizer the previous season. Storage nitrogen of peach was found to be high in autumn and winter but gradually lowered during the growing season. This nitrogen was utilized during the growing season and was reaccumulated in woody storage tissues after the cessation of shoot growth. Storage

nitrogen largely occurred as arginine in apple, plum, and the cherry as well as in peach trees (60, 61, 62, 63). In apples, most of the nitrogen mobilized for growth in the nitrogen rich tree came from roots, whereas in low nitrogen trees, this demand was met by the nitrogen from old shoot tissues. In macadamia, nitrogen deficiency symptoms developed when minimum leaf-N was below the range of 1.32 to 1.12 percent (21). Higher level of nitrogen increased plant girth and height of the macadamia tree with maximum growth achieved at 1.80 percent of leaf-N (32).

In the woody species of the Rosaceae family, nitrogen is mainly translocated as aspartic acid, asparigine, and glutamine (8, 9). In coffee, however, storage nitrogen is in the form of nitrate and higher concentration of this ion in the xylem sap of the coffee tree indicates the occurrence of nitrate reduction in the leaves. The average percentage composition of organic-N (aspartic acid, asparigine, and glutamine) of a deblossomed tree was 1.54. The leaves which represented only 31 percent of the total dry weight of the tree contained 55 percent of the organic nitrogen, although this figure varied with seasons (15, 59).

In most species of orchard crops, however, nitrate reduction occurs in the roots (8, 9, 10, 60). In this case nitrogen in the organic form may move upward through the phloem. The detection of high percentages of inorganic storage nitrogen in the xylem sap and leaves of coffee plants indicates that nitrate reduction

normally occurs in the top. The high accumulation of carbohydrates in the shoots of coffee plants suggests that evolution must have favored the translocation of nitrate to the leaves for reduction. At the fruiting season most of the dry matter is directed towards the developing fruits (13, 14, 15).

With this information in mind, a project was designed to investigate the critical period of nitrogen requirements in Kona Coffee and the optimum rate of this element. In addition, the influence of precipitation in N concentration of the coffee tree and whether or not coffee berry could serve as a sampling material in diagnostic purposes of N status of coffee were examined.

# MATERIALS AND METHODS

## Field Experiment

A field of Coffea arabica var typica, the major variety grown in the area was selected in 1974 at the Kona Experiment Station of the University of Hawaii. The trees aged about thirty years, were spaced at 2.44 m x 2.75 m. The field is on a gentle slope and the soil is of volcanic origin belonging to the Kealakekua family of Hydrol Humic Latosol Group (55).

There were eight trees to a plot. When the experiment was originally designed, no control plot was included. The design had three treatments with the objective of testing the period of application of fertilizers to control uniformity in anthesis. The first two treatments excluding the checks received 224 kg and 448 kg of N per hectare in March, and the third treatment consisted of 448 kg of N per hectare split into two applications, March and June. The Hawaiian (Beaumont-Fukunaga) pruning system was used with a 1-2-3-4- and 5-year-old branch on each tree, the 5-year-old branch was removed each year. Unfertilized trees from an outside field were used as a check. These treatments were arranged in a randomized complete block design. Concentrations of leaf- and berry-N during a fruiting cycle were determined and the analysis of variance was done on individual sampling dates and on a yearly basis, taking the effect of season into consideration. The means of leaf-N on seasonal basis were compared by using LSD. The

yield of red cherries for 1976-1977 and 1977-1978 were recorded and analyzed statistically to test the effect of nitrogen fertilizer rates.

The Fertilizer Material

The source of N was chosen on the basis of the availability of the fertilizer material. The fertilizer treatments were as follows: (A) In the first three years, 56 kg/ha each of N, $P_2O_5$ and $K_2O$ in March was supplemented with 168 kg N/ha as ammonium sulfate (20 percent) and 112 kg $P_2O_5$/ha as treble superphosphate (46 percent). In June this same plot received 56 kg/ha of $K_2O$ as muriate of potash 168 kg $P_2O_5$ as treble superphosphate; (B) the 448 kg N/ha received 56 kg/ha each of N, $P_2O_5$ and $K_2O$ as complete fertilizer supplemented with 392 kg N/ha as ammonium sulfate and 112 kg $P_2O_5$/ha as treble superphosphate in March. In June this plot received 56 kg of $K_2O$ and 168 kg/ha of $P_2O_5$; and (C) it is like treatment A with only the N rate repeated in June, that is 224 kg N/ha in March and 224 kg N in June. Since March 1978, the complete fertilizer was substituted with ammonium sulfate, treble superphosphate and muriate of potash as the sources of N, P and K, respectively. The fertilizer was spread around the canopy of the trees. The application was made on the first week of March and the first week of June in the appropriate plots.

The Sampling Procedure

Six of the eight trees per plot were selected at random. Since productive capacity of a stumped stem peaks during the third year in the Hawaiian pruning system (22), a three- or four-year-old vertical, growing upright was selected for leaf and berry sampling. In the majority of the trees, the first full bearing lateral at the time that the sampling started was the tenth branch from the top. As the test also included berry sampling, this primary branch was tagged for both leaf and berry sampling. In Hawaii as well as in most other places, leaves closer to the terminal of the branch are believed to be very sensitive to nitrogen concentration (16, 22, 52). Hence, the third pair of leaves from the terminal was selected for sampling, although occasionally, particularly in the dry season, limited growth of the tree forced sampling to be done on the fourth pair of leaves.

Under Kona rainfall conditions, where there is no distinctive dry period in some years, the distal buds keep differentiating. Hence, it was impossible to sample berries close to the leaf pair sampled, as the berries lacked uniformity from tree to tree. Thus, the berries were sampled from the first proximal node that bore fruit.

Beginning on June 8, 1977, sampling was done every 20 days until March 13, 1978. From April 1978 to August 1978 sampling was done every month. This change was made because only a slight change in results was observed between two consecutive sampling dates with

20-day intervals. The restriction of branches to the 10th primary lateral from the top also limited the amount of leaves collected from any particular tree. One leaf or two leaves, depending on availability, were collected from each tree and bulked on plot basis. The samples were always collected around 9:00 a.m. The leaves and berries were then dried in an oven at 75°C for a minimum of 5 days before they were ground to pass a 40 mesh screen.

Pot Experiment

This test was designed with the objective of determining the influence of nitrogen fertilizer rate on leaf- and berry-N content and growth of coffee plant by using a range of 0 - 560 kg of N/ha. Shortage of plant materials at the onset of the experiment forced the use of one plant per pot. The treatments were replicated four times in a randomized complete block and the replicates were divided into two groups--one group was deblossomed. The N levels included 0, 112, 224, 336, 448, 560 kg N/ha. Fifteen month old seedings of Coffea arabica var. typica were used. A 5-gallon plastic pot was one-third-filled with cinder at the bottom and the rest with soil. The plants were transferred into the pots in September 1977. After the trees had recovered from the transplanting shock, fertilizer applications began. Between October 1977 and May 1978 the annual dose was divided into six applications at regular intervals. The trees were watered three times a week and after every application of fertilizer. Leaf sampling on these trees was started in

January. One setback of this experiment was that some trees failed to recover from the transplanting shock. This was further aggravated by deblossoming in the higher nitrogen level.

## Tissue Analysis

The nitrogen analysis for this experiment was primarily done by the micro-Kjeldahl system developed by Cataldo, Shrader, and Youngs (18), and by Wall and Gehrke (66). The last few batches were analyzed in a slightly modified method developed by Wall and Gehrke (66) as the modified system had shown no difference when results of the two experiments were compared. In the digestion of sample, a model of technicon digestion block made by the Agricultural Engineering Department of the University of Hawaii was substituted for Technicon Block Digestor (BD-4D) system.

In the predigestion method nitrate-N was chemically reduced to ammonium-N. The digestion method converted protein and other forms of N to ammonium-N.

The solutions required for colorimetric development are: Solution A) 0.3 N NaOH; Solution B) 12.5 gm ethylenediamine tetra-actic acid (EDTA) in 500 ml of water adjusted to pH 10 with NaOH, and 10 ml of 0.25 percent methyl red in 60 percent ethanol; Solution C) 10 gm phenol and 100 mg sodium nitroferricyanate per liter of water, and Solution D) 10 gm NaOH, 7.06 gm $NaHPO_4 \cdot 7H_2O$ 31.8 gm $Na_3PO_4 \cdot 12\ H_2O$, and 10 ml 5 percent sodium hypochlorite per liter (18).

Methods

The ground sample of 50 mgm was weighed and added into the digestion tube. Half a gram of reduced Fe powder, 2 drops of antifoam reagent and 4 ml of 50 percent sulfuric acid were added to the tube for pre-digestion. After the tissue was gently but thoroughly mixed with the acid by a Vortex it was allowed to stand for 15 minutes before being transferred to a preheated water bath at 75°C. The temperature was raised to 95°C and allowed to pre-digest for 1 hour.

The tube was then removed from the water bath and allowed to cool. When it was cool enough, 1 gm of digestion catalyst and 6 ml of concentrated sulfuric acid were added and the content was gently mixed. The tubes were then placed in a heating block. The contents were digested at 320°C for 3-1/2 hours, when it turned green and clear. The tubes were then removed from the heating block and cooled. In the modified method adopted later, the nitrate-N was converted to ammonium-N by use of sulfuric acid selenium mixture and sodium sulfate. To 50 mg of sample, 7 ml of digestion mixture (5.8 gm $H_2SeO_3$ and 65 gm salicylic acid to a full bottle of reagent $H_2SO_4$, about 2.2 liters) and a heaping scoop of $Na_2SO_4$ were added. After half an hour, five drops of sodium thiosulfate solution was added and allowed to stand for an hour. Then 4 ml of 30 percent $H_2O_2$ was rapidly added. When the violent reaction had subsided, the tubes were inserted into a pre-heated block at approximately 450°C. Glass funnels were placed

at the mouth of the digestion tube 20 minutes later. The sample was shaken two hours later to wash down any sample adhering to the wall of the tube. An hour later when the contents turned green and clear, the tubes were removed from the heating block and cooled. The cooled contents were diluted with distilled water, the volume brought to 50 ml, and well-mixed by a magnetic stirrer.

One milliliter of the solution was transferred into a 100 ml volumetric flask, 2 ml of solution B were added and titrated with solution A. Ten ml each of solutions C and D were added and the color was allowed to develop in the next two to three hours before taking the colorimetric reading. In developing the standard, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2 ml of 2500 ppm of $(NH_4)_2\ SO_4$ were used.

# RESULTS AND DISCUSSION

## Rainfall Condition of Kona

The Kona region of the island of Hawaii, unlike other regions on the island, receives its heavy rain during the summer months. The winter months are dry. The seasonal rainfall regimes of Kona have been divided into three categories (24, 58). These are basically the same except that one study was more in relation to coffee growth period and production.

Investigation of the last five years' precipitation at the Kona Experiment Station reveals a decreasing total annual rainfall. The total annual rainfall in 1974 was 2056.38 mm. The total amount for 1977 was 1121.92 mm. This is close to an absolute minimum for coffee growth but the distribution had been fairly good. The five years' means and their standard errors are given in Table 1 and summarized in Fig. 1. There are highly significant differences among the rainfall means of the last five years.

The large fluctuation in annual rainfall is not an exception to this particular period. This fluctuation levels off some when running means of five or more years are considered (24). It is clear that the amount of precipitation and its distribution throughout the year are important factors in influencing coffee nutrition. The availability and absorption of nitrogen depend greatly on soil moisture level. Nitrogen is necessary for vegetative growth as well

TABLE 1

MONTHLY DISTRIBUTION OF RAINFALL EXPRESSED AS
MEANS OF A 5-YEAR PERIOD AND STANDARD ERRORS OF THESE MEANS
JUNE 1973 - JUNE 1978

| Month | Means Rainfall millimeters | Month | Means Rainfall millimeters |
|---|---|---|---|
| January | 75.23 ± 68.21[1] | July | 141.53 ± 52.94 |
| February | 72.74 ± 56.16[2] | August | 152.50 ± 64.07 |
| March | 113.59 ± 60.40 | September | 164.03 ± 129.24[2] |
| April | 144.83 ± 35.48 | October | 168.05 ± 89.22 |
| May | 183.69 ± 53.86 | November | 55.52 ± 46.86 |
| June | 208.03 ± 96.47 | December | 58.22 ± 34.98 |

1. P = 0.20

2. P = 0.10

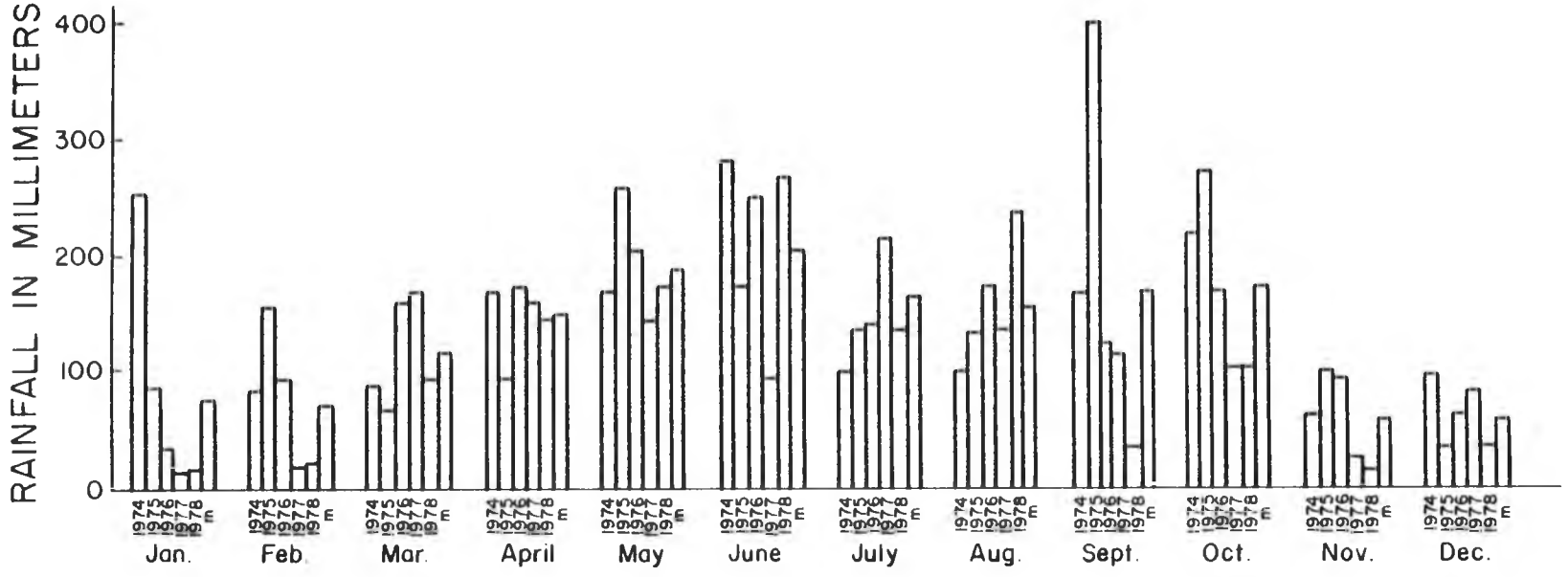


FIG. 1. RAINFALL - KAINALIU (KONA EXPERIMENT STATION) INCLUDING FIVE YEAR MEAN AND MONTHLY TOTALS FROM JUNE 1973 TO JUNE 1978.

as for the development of flowers and fruits.

Summary of rainfall during the experimental period is given in Fig. 2. It shows that the rainfall for most of the months during the experimental period fell short of the five-year mean. The low moisture level of the year may have contributed to the lower levels of leaf-N as will be seen later.

## LEAF NITROGEN

### Potted Plants

As has previously been described, the pot experiment was designed to give a gradient of N concentration in the coffee leaves with increasing levels of applied nitrogen. High doses of nitrogen (above 224 kg/ha) had drastic effects on the trees. The effect of high doses was severe on the deblossomed trees. Trees receiving 336 kg/ha or above suffered heavy defoliation and death in deblossomed trees. Trees with fruit did not have comparable damage. The defoliation and death of the deblossomed trees actually started prior to the removal of the buds. It is most likely that the effect of the higher levels of N was on the bark where water comes in contact with the bark. On a scale where severely damaged trees were given the lowest number (=1) and the best performing trees were given the highest number (=5), trees receiving 112 kg N per hectare performed best (Table 2).

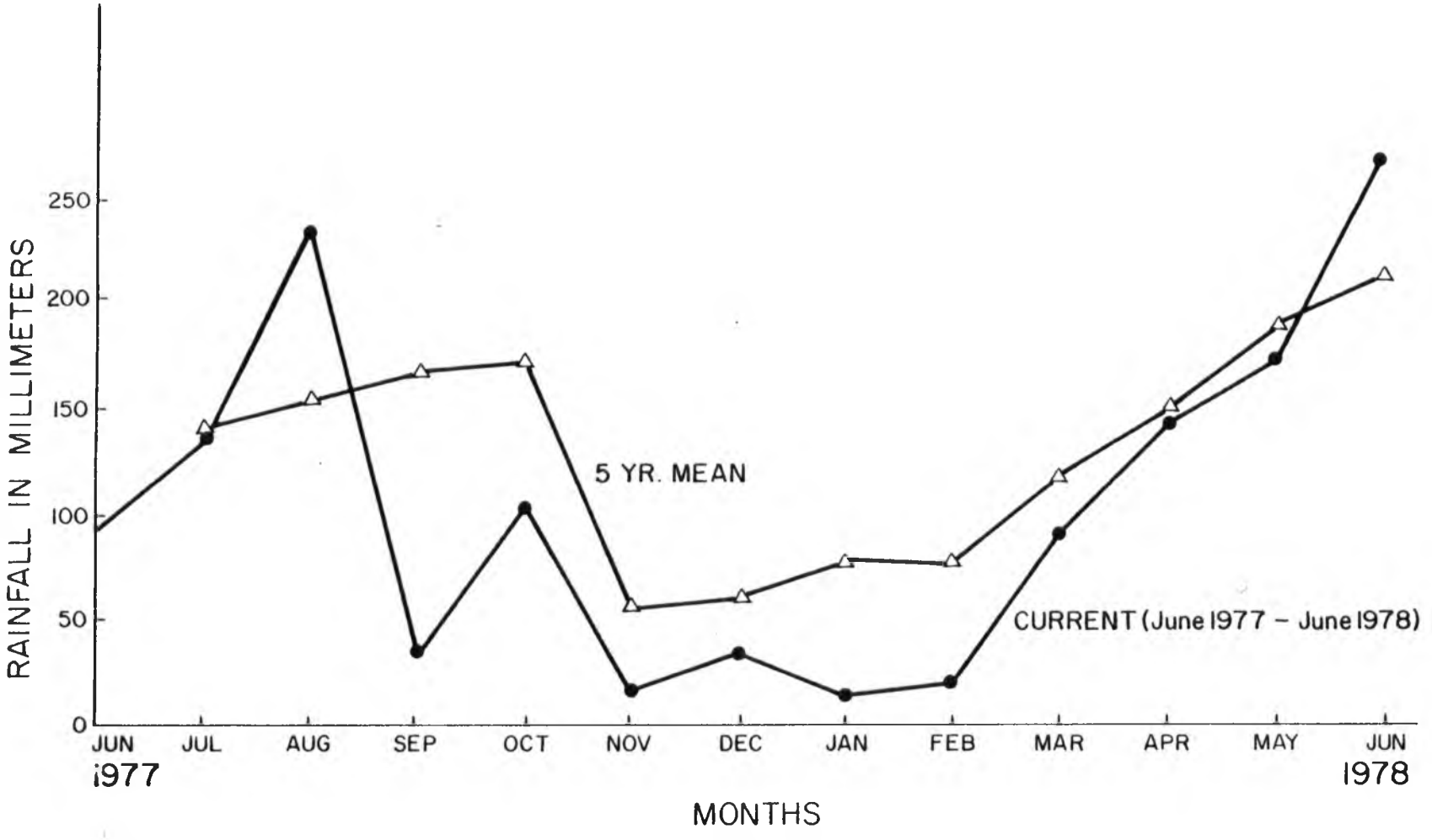


FIG. 2. DEVIATION OF MONTHLY RAINFALL OF CURRENT PERIOD IN KONA (JUNE 1977 - JUNE 1978) FROM THE FIVE YEAR MEAN.

TABLE 2

VISUAL RATINGS OF COFFEE TREES AS AFFECTED BY VARYING LEVELS OF N FERTILIZATION

| Kg N/hectare | Visual rating * |
|---|---|
| 0 | 2 |
| 112 | 5 |
| 224 | 4 |
| 336 | 3 |
| 448 | 2 |
| 560 | 3 |

* 1 = dead or severely damaged tree

2 = stunted growth or heavy defoliation

3 = poorly performing tree

4 = mild defoliation but still vigorous tree

5 = vigorous, productive looking tree

Data for total nitrogen content of leaves from plants receiving different levels of nitrogen fertilizers in the pot is given in Table 3 and summarized in Figs. 3 and 4. Except for plants receiving 224 kg/ha of N, all others seemed to follow similar patterns (Fig. 4). From Figure 3 it is seen that the mean leaf-N levels off at about 3.65 percent at applied N levels of between 224 kg and 336 kg N/ha. Although concentrations of leaf-N above 5 percent were recorded during the course of the experiment, the average leaf-N for all treatments was 3.18 percent for fruiting trees and 3.01 percent for defruited trees (Table 3).

One of the purposes of deblossoming the trees was to compare the N-level of the leaf with its counterpart in fruiting trees. In Table 4 concentration of leaf-N for plots receiving 224 kg/ha is shown for deblossomed and fruiting trees until sample collection was terminated. Visually, trees receiving 224 kg/ha were not the best performing ones (see Table 2).

The concentration of leaf-N for trees receiving 336 kg/ha or above was not consistent in the early parts of fruit development but later, as fruit development continued, increasing levels of fertilizer gave increasing concentration of leaf-N. Height measurement of new growth did not show that the 224 kg N/ha plot to have the greatest growth (Table 5).

The important factor to consider from this experiment is that the trees receiving fertilizer application regularly and being

TABLE 3

THE EFFECT OF DIFFERENT RATES OF N FERTILIZER ON PERCENT OF LEAF-N ON POT EXPERIMENT FROM JANUARY TO JUNE (1978)

a. Blossoms removed*

| Treatments | 1/11 | 1/30 | 2/21 | 3/13 | 4/10 | 5/10 | 6/13 | Mean |
|---|---|---|---|---|---|---|---|---|
| Kg N/ha | Percent of Leaf-N | | | | | | | |
| 1. Control | 1.34 | 1.56 | 2.01 | 1.93 | 1.78 | 1.50 | 1.38 | 1.64 |
| 2. 112 | 3.16 | 3.33 | 2.77 | 2.70 | 2.95 | 4.21 | 2.24 | 3.05 |
| 3. 224 | 3.90 | 5.10 | 4.39 | 3.90 | 4.03 | 3.44 | 3.47 | 4.35 |
| 4. 336 | | | | | | | | |
| 5. 448 | 3.25 | 3.00 | 3.41 | | | | | |
| 6. 560 | | | | | | | | |

b. Blossoms not removed

| Treatments | 1/11 | 1/30 | 2/21 | 3/13 | 4/10 | 5/10 | 6/13 | Mean |
|---|---|---|---|---|---|---|---|---|
| Kg N/ha | Percent of Leaf-N | | | | | | | |
| 1. Control | 1.82 | 2.48 | 2.14 | 2.12 | 2.18 | 1.46 | 1.56 | 1.97 |
| 2. 112 | 3.02 | 3.80 | 3.31 | 2.82 | 2.88 | 2.63 | 3.195 | 3.12 |
| 3. 224 | 3.78 | 4.48 | 4.02 | 4.29 | 3.53 | 2.05 | 3.10 | 3.61 |
| 4. 336 | 2.92 | 3.10 | 2.99 | 3.57 | 3.08 | 2.60 | 3.13 | 3.06 |
| 5. 448 | 3.41 | 3.67 | 3.61 | 3.73 | 3.46 | 3.59 | 3.84 | 3.62 |
| 6. 560 | 2.70 | 3.66 | 3.96 | 3.73 | 3.83 | 3.94 | 4.08 | 3.70 |
| Mean | 2.94 | 3.53 | 3.34 | 3.38 | 3.16 | 2.71 | 3.15 | 3.18 |

*Trees in this set receiving 336, 448 and 560 kg N/ha failed to recover from the transplanting shock. Later they were damaged by the high dose of N.

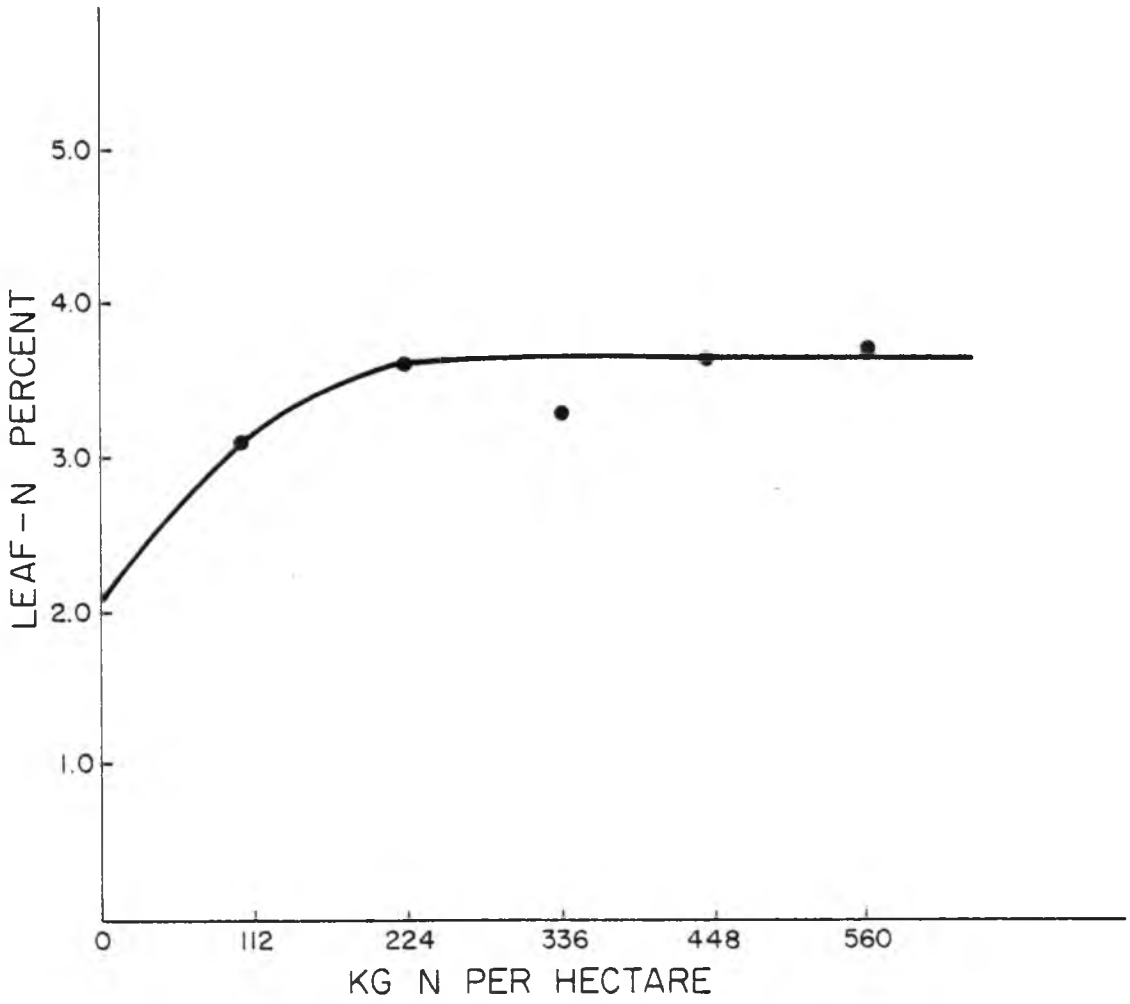


FIG. 3. EFFECT OF INCREASING LEVELS OF NITROGEN FERTILIZER ON CONCENTRATION OF LEAF NITROGEN IN *COFFEA ARABICA* L. (POT EXPERIMENT).

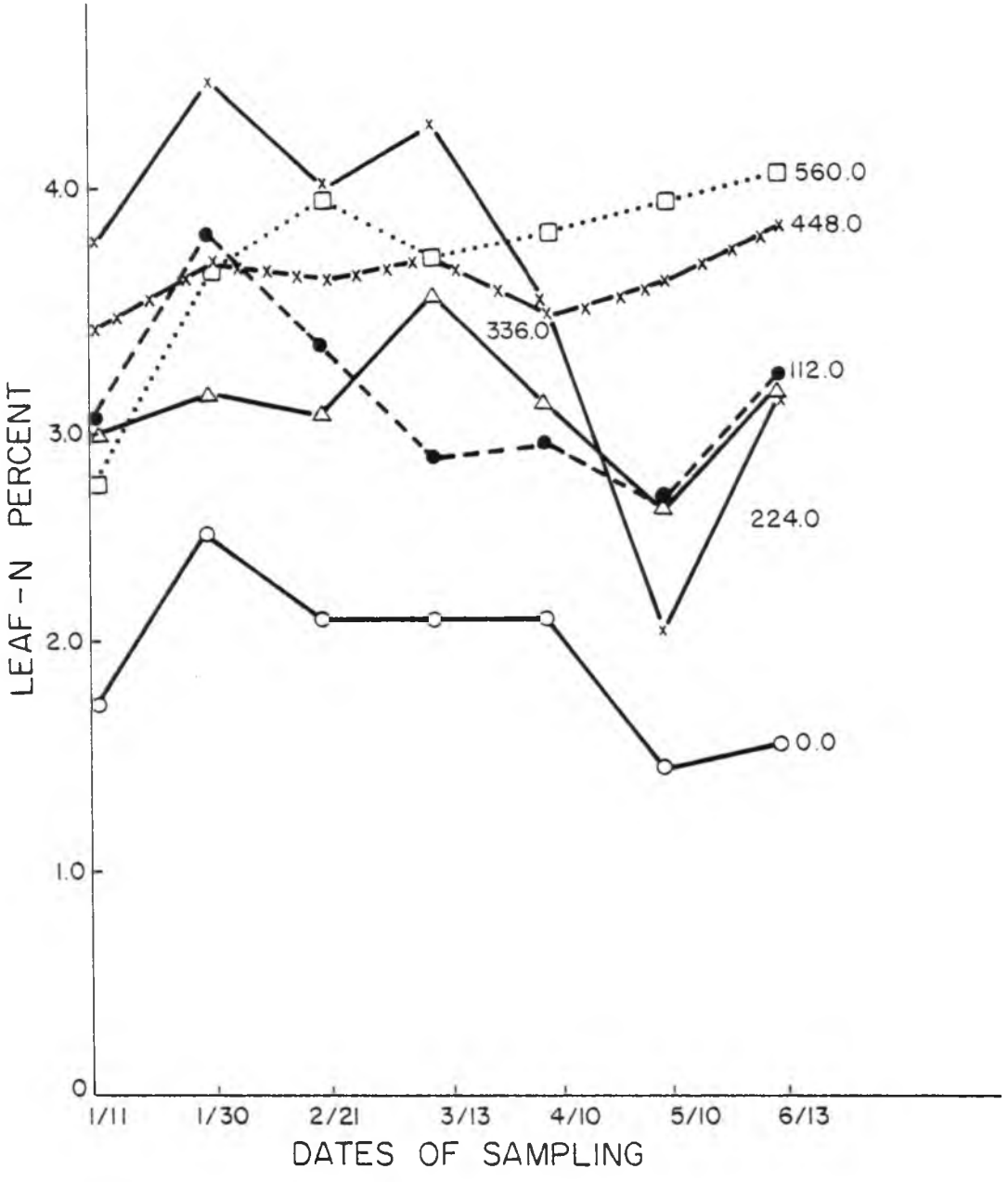


FIG. 4. THE CHANGE IN LEAF-N IN COFFEE PLANTS RECEIVING DIFFERENT LEVELS OF NITROGEN FERTILIZER AT REGULAR INTERVALS DURING THE FRUITING PERIOD (POT EXPERIMENT).

TABLE 4

THE INFLUENCE OF FRUITS ON PERCENT OF LEAF-N FOR TREES RECEIVING 224 KG N $HA^{-1}$ FROM JANUARY TO JUNE 1978 (POT EXPT.)

| Buds | 1/01 | 1/30 | 2/21 | 3/13 | 4/10 | 5/10 | 6/13 | Mean |
|---|---|---|---|---|---|---|---|---|
| Removed | 3.90 | 5.10 | 4.39 | 3.90 | 4.03 | 3.44 | 3.47 | 4.35 |
| Not removed | 3.78 | 4.48 | 4.02 | 4.29 | 3.53 | 2.05 | 3.10 | 3.61 |

LSD, 5%: between bud means 0.24% N; LSD, 1% between bud means 0.36% N.

TABLE 5

CHANGE IN HEIGHT OF COFFEE TREES INFLUENCED BY RATES OF NITROGEN FERTILIZATION (POT EXPERIMENT)

| Treatment Kg N/ha | Change in Height in cm |
|---|---|
| 0 | 11.00 |
| 112 | 38.25 |
| 224 | 28.00 |
| 336 | 34.00 |
| 448 | 24.00 |
| 560 | 22.00 |

LSD, 5%: 6.94 cm and 1%: 10.90 cm between nitrogen fertilizer rates.

watered routinely show some uniformity in leaf-N concentration. Particularly, the split application of nitrogen fertilizer keeps leaf-N concentration constant throughout the season.

Field Experiment

Nitrogen concentration with respect to tree height from different sampling position was tested. A set of leaves collected from the 20th branch from the top were compared with that from the 10th branch. At another time, leaves sampled from the 3rd branch from the top were also compared with leaves collected from the 10th branch. These leaves occupied the same position on each branch. The comparisons show that they have about the same mean of leaf-N (Table 6).

The concentration of coffee leaf-N per sampling date in field trees receiving different rates of N or at different times of application is shown in Table 7. Leaf-N varied according to the amount of precipitation during the month (Fig. 5). Particularly in the dry season, there was an overlapping of leaf-N in trees that received different levels of N. On the first two sampling dates, separate samples were also collected from an abandoned field which had not been fertilized for several years. This was done to survey the status of leaf-N on well-managed or fertilized trees versus neglected trees. When the means of leaf-N including this sample were compared, the well-managed plots had a significantly higher

TABLE 6

THE INFLUENCE OF SAMPLING POSITIONS ON THE DISTRIBUTION OF NITROGEN IN LEAVES OF *COFFEA ARABICA* L. *

| Kg N/ha | April Branch | | August Branch | |
|---|---|---|---|---|
| | 10th | 20th | 10th | 3rd |
| 0 | 2.06 | 2.08 | 2.39 | 2.39 |
| 224 | 2.62 | 2.79 | 2.52 | 2.44 |
| 448 | 2.77 | 2.80 | 2.63 | 2.46 |
| 224 x 2 | 2.58 | 2.43 | 2.59 | 2.45 |
| Mean | 2.51 | 2.52 | 2.53 | 2.41 |

*The means are not significant.

TABLE 7

THE EFFECT OF RATES OR TIME OF APPLICATION OF N FERTILIZER ON LEAF-N OF *COFFEA ARABICA* ON FIELD EXPERIMENT

| Description kg N/ha | 6/8/77 | 6/28 | 7/18 | 8/8 | 8/29 | 9/19 | 10/11 | 10/31 | 11/21 | 12/12 | 1/3/78 | 1/30 | 2/21 | 3/13 | 4/10 | 5/10 | 6/13 | 7/10 | 8/10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 1.74 | 1.94 | | | | | | | 1.97 | | 1.52 | | | | | | | | |
| 0 | 3.16 | 2.17 | 2.95 | 2.56 | 3.07 | 2.73 | 2.82 | 2.16 | 2.40 | 2.35 | 1.91 | 1.86 | 2.07 | 1.96 | 2.06 | 1.67 | 2.04 | 2.43 | 2.39 |
| 224 (March) | 3.04 | 2.87 | 3.13 | 2.82 | 3.03 | 2.93 | 2.89 | 2.06 | 2.53 | 2.96 | 2.25 | 2.10 | 2.14 | 2.33 | 2.62 | 2.23 | 2.44 | 2.49 | 2.52 |
| 448 (March) | 3.23 | 2.56 | 3.09 | 3.12 | 2.94 | 2.88 | 2.59 | 2.22 | 2.56 | 2.42 | 2.46 | 2.19 | 2.14 | 2.41 | 2.77 | 2.56 | 2.47 | 2.49 | 2.63 |
| 224 x 2 (March, June) | 3.01 | 2.87 | 3.27 | 3.12 | 2.93 | 2.82 | 2.67 | 2.33 | 2.72 | 2.56 | 2.13 | 2.29 | 2.31 | 2.41 | 2.58 | 2.29 | 2.48 | 2.58 | 2.59 |
| Mean | 3.11 | 2.62 | 3.11 | 2.90 | 2.99 | 2.84 | 2.74 | 2.19 | 2.55 | 2.57 | 2.19 | 2.11 | 2.17 | 2.27 | 2.50 | 2.19 | 2.36 | 2.50 | 2.53 |
| F-test | incl. S*** | incl. S* | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | 5% | 5% | N.S. | 5% | 1% | 5% | 5% | N.S. | N.S. |
| | -S N.S. | 0* | | | | | | | | | | | | | | | | | |
| S.E. | 0.058 | 0.204 | 0.158 | 0.19 | 0.15 | 0.177 | 0.14 | 0.158 | 0.175 | 0.155 | 0.092 | 0.087 | 0.082 | 0.086 | 0.1 | 0.159 | 0.084 | 0.059 | |

S = Sample collected from abandoned field

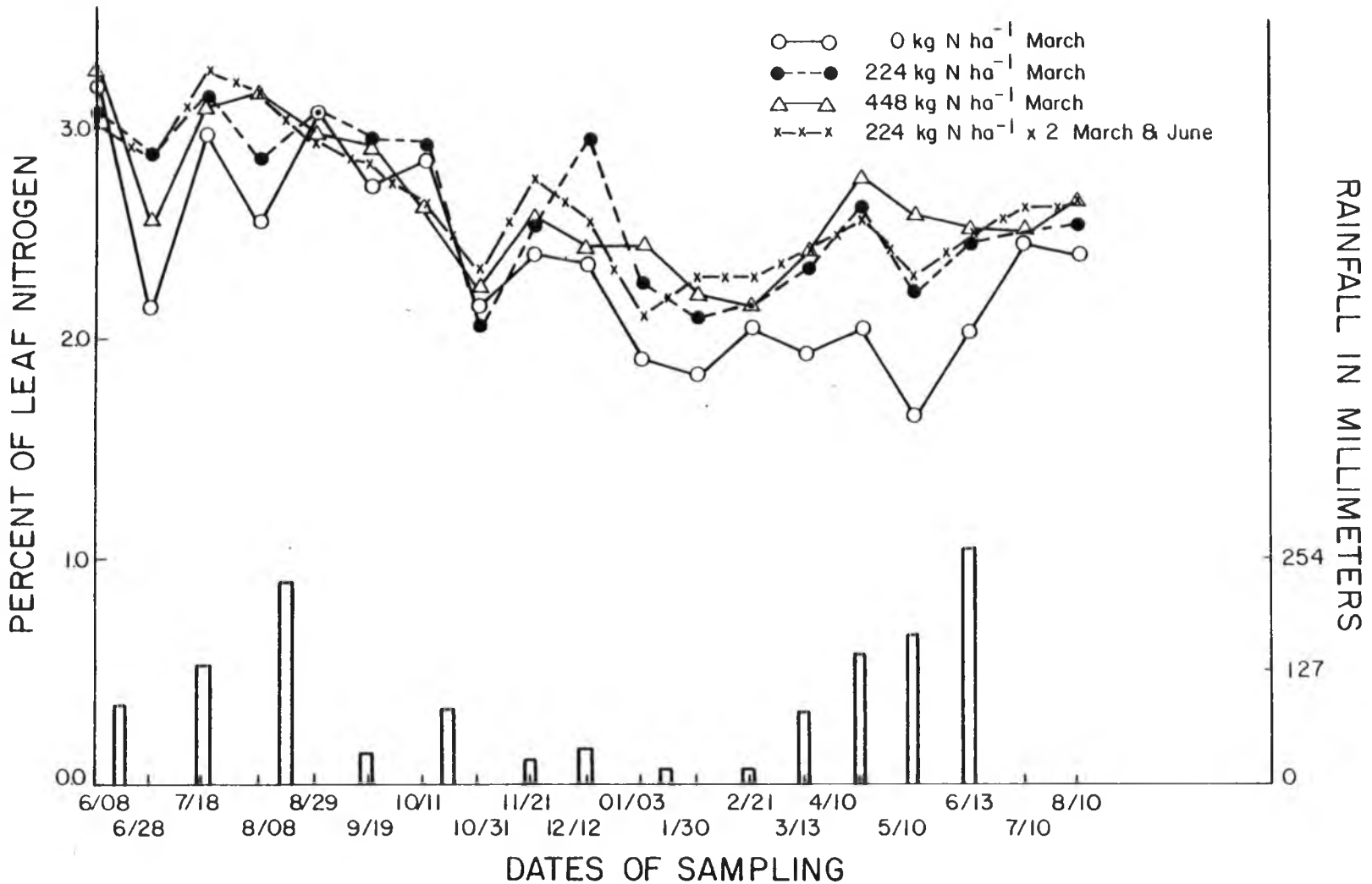


FIG. 5 THE EFFECT OF NITROGEN FERTILIZER ON THE LEVELS OF LEAF-N C. ARABICA L. SAMPLED IN A YEARLY CYCLE.

leaf-N. As fruit maturity and ripening were maximum in November, leaf-N dropped in the experimental field but it remained high (ca 1.88 $\pm$ 0.059) in the abandoned plot. Another sampling from this plot in January showed a reduction in leaf nitrogen. Further sampling from this plot was not possible because the trees were stumped down. A close investigation of the graph in Figure 5 shows that in the summer, with higher rainfall, leaf-N rises. It should also be borne in mind that the June application of N is probably one of the reasons for high nitrogen in the leaves.

Apart from the unfertilized plot, levels of nitrogen fertilizer and/or the time of application showed no significant difference in leaf-N means. In the wet season, at the beginning of the experiment even the unfertilized plot had about the same leaf-N means as the plots receiving different levels of N. In the dry season, however, analysis of leaf-N for individual samplings showed significant differences between leaf-N means. From January 1978 to May 1978 leaf-N mean for the nitrogen treated plots were significantly higher than the unfertilized plot. During the dry season only in February the means of leaf-N were not significantly different from the check.

The Effect of Seasonal Variation on Leaf-N Means

In the summer months of 1977 leaf-N was high in nearly all of the sampling. The average leaf-N from June 1977 to May 1978 on the basis of seasonal variation is given in Table 8.

TABLE 8

THE EFFECT OF SEASONAL VARIATION ON LEAF-N CONCENTRATION OF *COFFEA ARABICA* L. RECEIVING DIFFERENT RATES OF N-FERTILIZER

| N Treatments Kg $ha^{-1}$ | June-Oct77 | Nov 77-Feb78 | Mar-May 78 | June-Aug 78 | Mean |
|---|---|---|---|---|---|
| 0 | 2.68 | 2.12 | 1.90 | 2.29 | 2.25 |
| 224 x 1 March | 2.82 | 2.37 | 2.40 | 2.48 | 2.52 |
| 448 x 1 March | 2.77 | 2.40 | 2.58 | 2.53 | 2.58 |
| 224 x 2 March & June | 2.86 | 2.40 | 2.45 | 2.55 | 2.56 |
| Season Mean | 2.78 | 2.32 | 2.33 | 2.46 | |

LSD, 5%: between season means 0.116% at 1%; LSD among N level means at 5%, 0.150; at 1%, 0.20% leaf-N.

The data are also summarized in Figure 6. It is seen that percent of leaf-N dropped gradually to 2.1 percent in January, the lowest monthly mean of all recording. Then it gradually rose again. The average percentage of leaf-N during the summer months of 1977 including October was 2.78. Except for the sampling done in June 28, 1977 sample date, all levels of N fertilizer applied had about the same leaf-N during this period. Data from the abandoned plot is not included in this comparison. However, leaf-N started to decline starting from August. The leaf-N concentration for the check plots covering this period had about the same mean as trees receiving different levels of N. Trees on the unfertilized plots had very light crops compared to the N-treated trees. Flowering on these unfertilized trees was also late, leading to a late crop.

In the period from November 1977 to February 1978, only in the month of January was there a significant difference in leaf-N of the treated plots over the unfertilized plots. Comparison of the January data with that obtained from the abandoned plot showed a highly significant increase in concentration of leaf-N of the treated plots. At this time most of the crop had been harvested. Trees receiving 224 kg N/ha in March had about the same mean of leaf-N as trees receiving 448 kg N/ha on the same date. Split application of the 448 kg N gave about the same percent of leaf-N as the other levels or time of application. The concentration of leaf-N seemed to have increased in April over the preceding month.

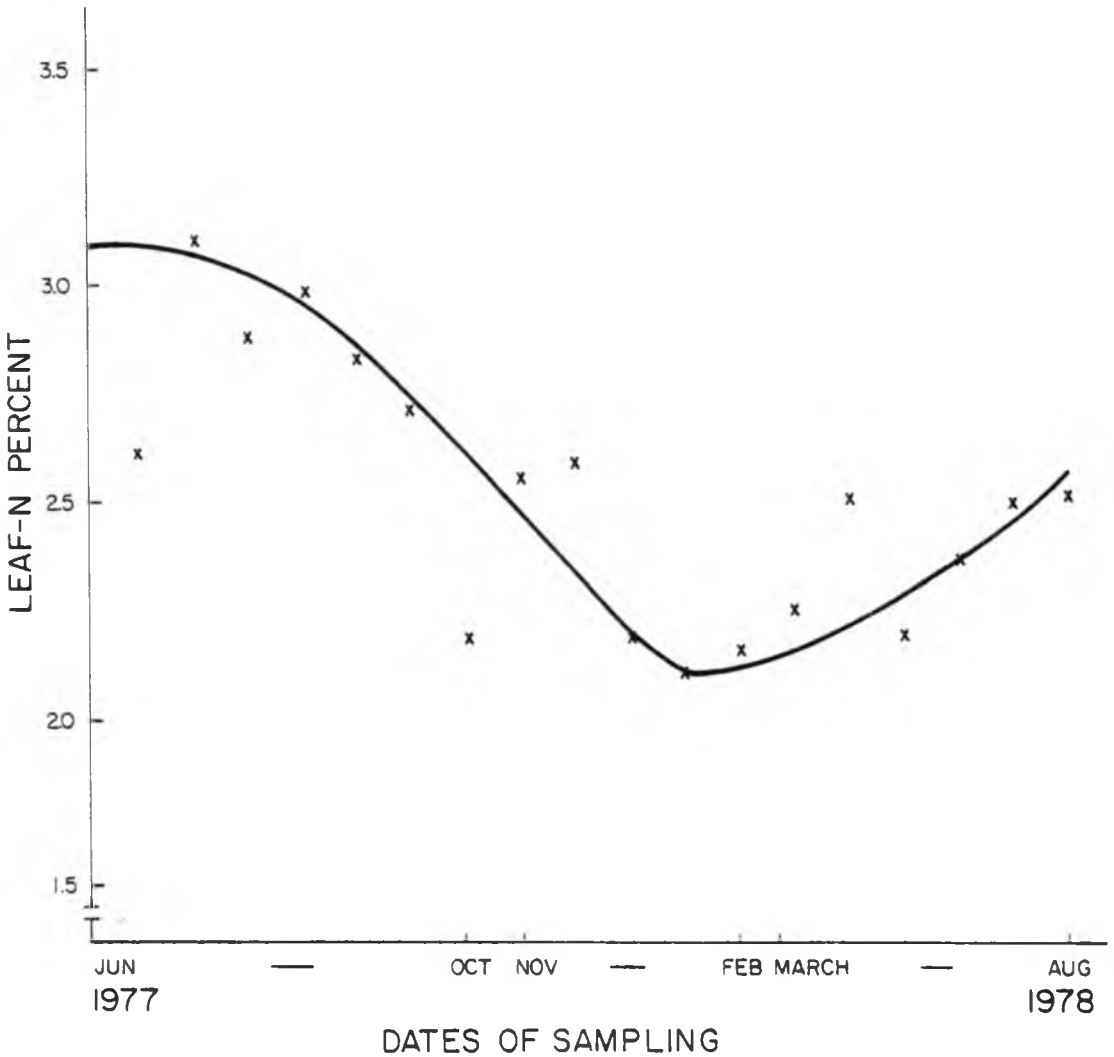


FIG. 6 THE EFFECT OF SEASONS ON THE NITROGEN CONCENTRATION IN COFFEE LEAVES AS PERCENT OF D/WT.

However, this increase dropped in the May and June sampling. Upon investigation it was found that there was a precipitation of 24.13 mm the day before the sample was collected, on April 9. This amount seemed to be high enough to affect leaf-N concentration when compared with the precipitation on the days before sample collection in other months. It is evident, however, that the level of leaf-N done with the onset of the wet season. It was with the onset of the wet season of 1978 that the treated trees show a higher level of nitrogen in the leaves over the non-treated trees.

The means of leaf-N were compared among the three seasons indicated above. There is a highly significant difference among the concentration of leaf-N means due to the effect of season (Table 9). In the summer of 1977 from June to October the average N percentage of eight samplings was 2.78. This confirms earlier results that during the wet season leaf-N is about 2.75 percent (11). However, the November through February and March through May samplings had about the same mean (2.32 percent and 2.33 percent respectively). These results are shown in Table 9. Tests for nitrogen fertilizer level covering all seasons show that it is highly significant. However, this difference is attributed to all nitrogen treatments compared to the control. The 448 kg N in single or split application is no better than the 224 kg applied once. The spring months of 1977 had higher rainfall (466.60 mm) and better distribution than

TABLE 9

ANALYSIS OF VARIANCE FOR PERCENT OF LEAF OF COFFEE TREES RECEIVING DIFFERENT RATES OF NITROGEN FERTILIZER ON SEASONAL AVERAGES (JUNE 1977-MAY 1978)

| SOURCE | df | SS | MS | F |
|---|---|---|---|---|
| Total | 47 | 4.48 | | |
| Season (Main Plots) | (11) | 2.37 | | |
| Block | 3 | 0.03 | 0.01 | <1 |
| Season | 2 | 2.23 | 1.12 | 61.94** |
| Error (a) | 6 | 0.11 | 0.018 | |
| N level | (4) | 1.00 | 0.33 | 10.33** |
| Control vs. N-treatment | 1 | 0.81 | 0.81 | 25.31** |
| Among N-treatment | 2 | 0.19 | 0.095 | 2.97 N.S. |
| S X N | 6 | 0.37 | 0.062 | 1.92 N.S. |
| Error (b) | 27 | 0.88 | 0.032 | |

** Indicates significant at P = 0.01

during the same period in 1978 (391.92 mm). This would favor N absorption and distribution.

Nitrogen Concentration of the Berries

Along with leaf sampling, berries were collected from the same branch for nitrogen analysis. In 1977 sample collection was started in the first week of June, about two and a half months after flowering. Berry sample collection was continued until fruit ripening. In 1978 berry sample collection was started six weeks after flowering. Percent of berry nitrogen on dry weight basis for individual sampling dates is given in Table 10 and summarized in Fig. 7. Nitrogen concentration in the berries was higher in the wet months but it gradually decreased as fruit maturity and ripening approached. Berry samples collected from November to the end of harvest included fully mature or ripe cherries and thus had low percentage of nitrogen on dry weight basis.

Analysis for nitrogen concentration in the berries showed that for almost all the sampling dates berry-N concentration did not increase with increasing level of nitrogen fertilizer. However, analyses of the berries for N from the pot experiment show that increasing levels of applied nitrogen had also increased nitrogen concentration in the berries (Table 11). The control plots of the pot experiment had stunted growth. Thus crop production was almost nil making it difficult to make comparisons.

TABLE 10

THE EFFECT OF DIFFERENT RATES OR TIME OF APPLICATION OF N ON CONCENTRATION OF N IN COFFEE BERRIES

| | 1977 | | | | | | | | | | | 1978 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kg N/ha | 6/08 | 6/28 | 7/18 | 8/08 | 8/29 | 9/19 | 10/11 | 10/31 | 11/21 | 12/12 | 1/03 | 5/10 | 6/10 | 7/10 | 8/10 |
| S. Abandoned Field | 2.45 | 1.81 | | | | | | | 1.42 | | | | | | |
| 0 | 2.48 | 2.29 | 2.58 | 1.90 | 2.56 | 2.08 | 1.91 | 1.78 | 2.11 | 1.75 | 1.78 | 2.13 | 1.96 | 1.96 | 2.10 |
| A. 224 | 2.77 | 2.33 | 2.59 | 1.80 | 2.29 | 2.36 | 2.03 | 1.82 | 1.88 | 2.03 | 1.82 | 2.42 | 2.13 | 1.90 | 1.97 |
| B. 448 | 2.74 | 2.41 | 2.49 | 2.23 | 2.54 | 2.20 | 2.03 | 1.92 | 1.91 | 1.51 | 2.08 | 2.63 | 2.04 | 1.96 | 2.04 |
| C. 224 x 2 | 2.73 | 2.24 | 2.57 | 1.94 | 2.32 | 2.18 | 1.74 | 1.79 | 1.84 | 1.86 | 2.02 | 2.37 | 2.10 | 1.99 | 2.23 |
| | * | * | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | * | N.S. | N.S. | N.S. |

N.S. = not significant at P = 0.05
* = significant at P = 0.05

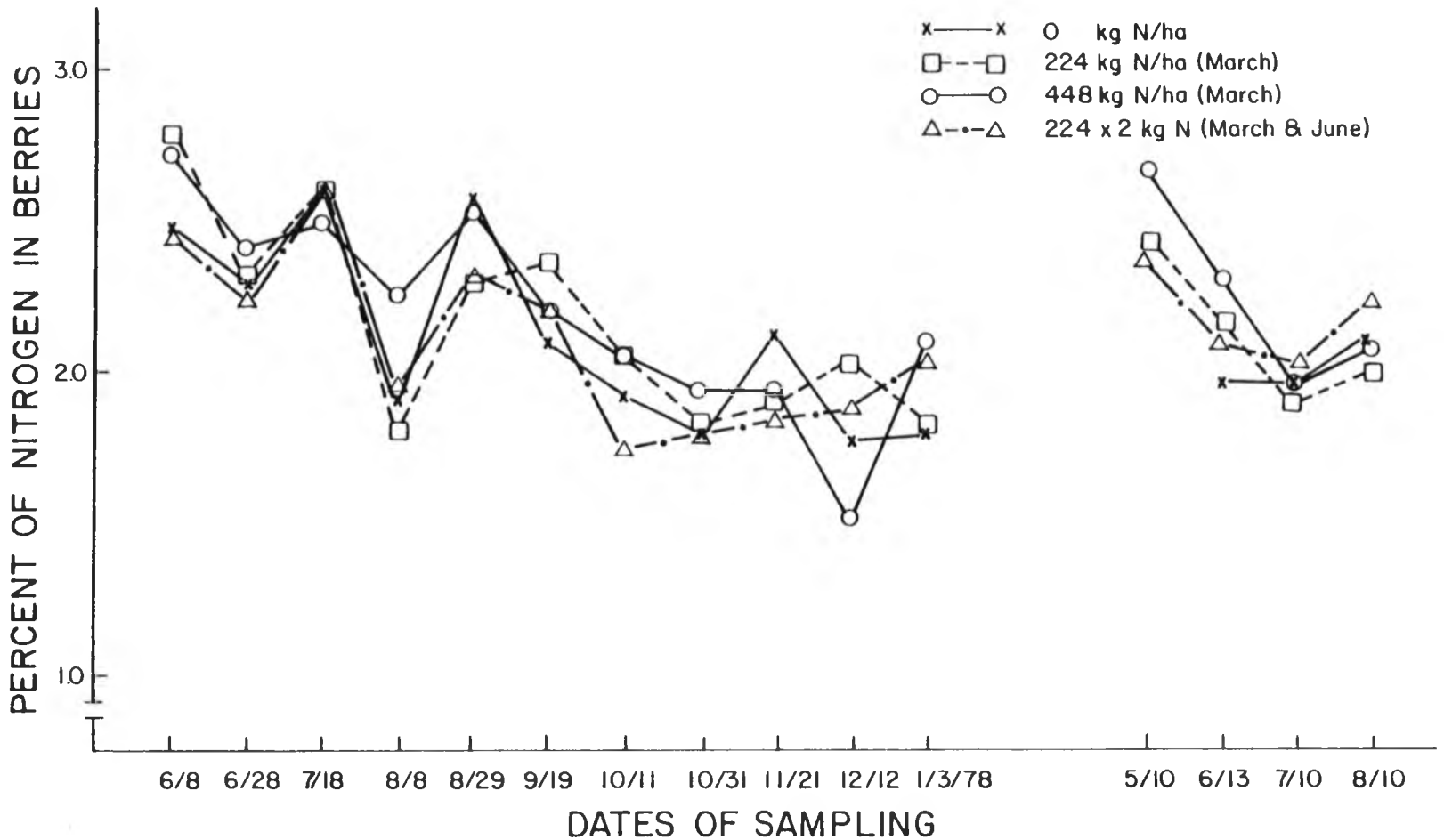


FIG. 7 THE EFFECT OF RANGES OF NITROGEN FERTILIZER ON NITROGEN CONCENTRATION OF COFFEE BERRIES DURING FRUIT GROWTH.

TABLE 11

EFFECT OF DIFFERENT RATES OF NITROGEN FERTILIZER OR TIME OF APPLICATION ON COFFEE BERRY-N IN THE POT EXPERIMENT

| N levels | Percent Berry-N on Dry Weight | | |
|---|---|---|---|
| Kg/ha | May | June | Mean |
| 0 | - | - | - |
| 112 | 2.35 | 2.06 | 2.20 |
| 224 | 2.22 | 2.37 | 2.30 |
| 336 | 2.20 | 2.64 | 2.42 |
| 448 | 2.56 | 2.95 | 2.76 |
| 560 | 3.35 | 3.37 | 3.36 |

LSD, 5%: between N treatment means 0.46% N; LSD, 1%: 0.67% N.

The Effect of Nitrogen on Cherry Yields

Two years of yield data were considered here. Fertilizer application was begun in March 1975. Cherry yield for 1976-77 was recorded. Leaf and berry sample collection was begun in June 1977. Yield of 1977-78 was also recorded. Results of the two years are given in Table 12 which is also summarized in Fig. 8. As no check plots were included in the original design, yield data is only available for nitrogen treated plots. Investigation for the effect of different levels of nitrogen shows no significant influence of nitrogen fertilizer on coffee yield (Table 13). The coffee yield for the two years have about the same mean, although numerically the 1976-77 season is higher than the 1977-78 season yield.

TABLE 12

EFFECT OF NITROGEN FERTILIZER ON CHERRY YIELD OF *COFFEA ARABICA* L. RECEIVING DIFFERENT LEVELS OR TIME OF APPLICATION

| Nitrogen level/ Time of Application | Quintals/hectare* 1976/77 | 1977/78 | Mean+ |
|---|---|---|---|
| 224 Kg N/ha (March) | 146.41 | 132.78 | 139.60 |
| 448 Kg N/ha (March) | 139.23 | 137.52 | 138.38 |
| 224-224 Kg N/ha (March & June) | 143.26 | 135.89 | 139.58 |
| Mean | 142.97 | 135.40 | |

* See Appendix for unit conversion.
\+ The means are not significant.

TABLE 13

THE ANALYSIS OF VARIANCE TABLE FOR COFFEE YIELDS
(QUINTALS PER HECTARE)

| Source of Variation | df | SS | MS | F |
|---|---|---|---|---|
| Total | 23 | 17479.94 | | |
| Main Plots (Nitrogen) | 11 | 11006.03 | | |
| Block | 3 | 5269.47 | 1756.49 | 1.84 |
| Nitrogen | 2 | 7.47 | 3.74 | <1 |
| MP error (N x B) | 6 | 5728.77 | 954.80 | |
| Year | 1 | 343.68 | 343.68 | <1 |
| N x Year | 2 | 142.38 | 71.19 | <1 |
| B x Y | 3 | 2681.38 | 893.79 | 1.34 |
| B x Y x N | 6 | 3306.47 | 551.08 | <1 |
| [subplot error | 9 | 5987.85 | 665.32 | ] |

cv = 18.53 percent

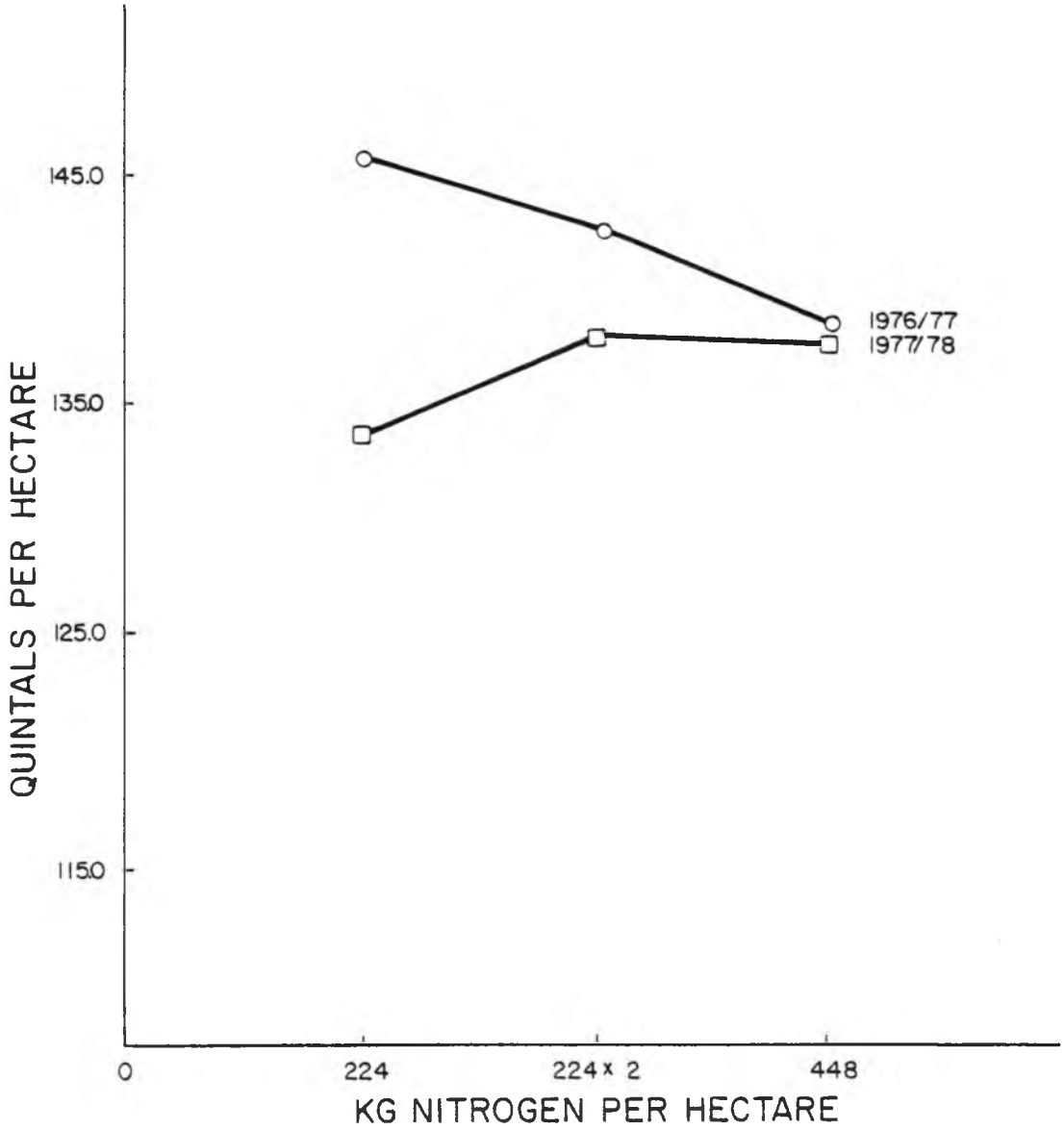


FIG. 8. THE EFFECT OF NITROGEN FERTILIZER ON THE YIELD OF COFFEA ARABICA L. (RED CHERRIES).

Results of the analyses show that concentration of nitrogen both in the leaves and the berries is higher during the wetter seasons. In contrast, soil nitrate-nitrogen tends to decrease during the wet season (51). Nitrate uptake by the tree from the soil is accelerated during the wetter season. In 1978, the majority of the field trees had anthesis on March 12. Leaf sample collected on the thirteenth of March gave leaf-N higher than the previous month. Although leaf nitrogen remained higher in the subsequent months, this confirms Carvajal, et al., (17) finding that nitrate uptake increases during short periods prior to anthesis.

It was reported that anthesis occurs within eight to ten days after the first heavy shower following a dry spell (40, 68). Carvajal, et al., (17) also found that nitrate uptake is reduced during anthesis. The day prior to anthesis can be considered as the date of anthesis, thus reducing leaf-N concentration. However, the results do not verify this statement. The higher levels of leaf-N during the summer months of 1977 and 1978 confirm the fact that there is an increased absorption of nitrate during periods of vegetative growth. Leaf-N increased from 2.27 percent in March to 2.50 in April 1978. The concentration of leaf-N in March although higher than the preceding month is still lower than that of April probably because of the low absorption of nitrate by the tree during anthesis. The higher level of total N (2.84 percent) observed at

fruit maturity (Table 7, September mean) when compared to periods of fruit ripening (2.55 percent in November) or prior to flowering (2.17 percent in February) indicates an increased absorption of N in periods of heavy demand (17).

A bearing tree facing nitrogen deficiency passes its nitrogen from the lower part of the tree to the developing fruit and growing shoots. When the deficiency is intense, the leaves abscise and only berries are seen at the node. The translocation of nitrogen from older leaves to younger shoots and developing fruits takes place when N in the form of proteins and some free amino acids dissolve and are retranslocated, a phenomena with most tree plants. The uptake and accumulation of N in the berries is parallel with the rise in the dry matter percentage of the berries (15). Three distinct periods of accumulation of N in the berries may be due to (a) a high initial accumulation of N in fruit wall after which there appears to be a fall in N content which may be due to a redistribution of N to different parts; (b) a preferential accumulation of N by the endosperm from 150 days onwards indicating more translocation of nutrients to synthetic sites (developing seeds), and (c) also translocation of nutrients and carbohydrates from leaves to berries (43). In apple trees (9, 10, 62) most of the nitrogen which was mobilized for growth in N-rich apple trees came from the roots, whereas in low-N trees most of the mobilized N came from old shoot tissue. In contrast, in peaches, between 60 to 80 percent of the

storage N in dormant, young trees was present in root tissue irrespective of the previous nitrogen treatment (61).

Concentration of Nitrogen in Leaves

The total nitrogen concentration of coffee leaves may show a wide variation. Although some of the control plots in both the pot and in the field experiments have occasionally shown a concentration of less than 1 percent, the critically low range was between 1 - 2 percent. In these trees the low concentration of leaf nitrogen was only slightly affected by seasonal changes. The control plants of the pot experiment (Fig. 3) and leaf sample collected from the abandoned plots show this (Table 7). Trees with leaf-N concentration below 2 percent for an extended period of time exhibited stunted growth, leaf chlorosis and die-back. In the field trial, trees receiving nitrogen treatments have not shown severe deficiency problems but some heavy bearing trees have indicated minor die-back signs, perhaps due to low N.

The increase of total nitrogen in the leaves after the beginning of the rainy season paralleled the onset of growth and flowering. The N concentration gradually decreased according to the amount of available N in the soil and to the stress induced by the maturity of the crop. The decline in growth which is usually observed at fruit ripening or after, may be attributed to the low N availability in the soil or depletion from the tree by the crop and/or it may be due to the depletion of starch which is the most important contributing factor in growth and fruit development.

In Hawaii, 2.0 - 3.25 percent leaf-N has been considered normal or adequate (20, 26). Elsewhere (43) the critical level runs anywhere between 1.20 percent - 3.0 percent of leaf-N. However, determination of the normal range would depend on the techniques of leaf sampling and analysis, the condition of the tree, the time and period of sample collection.

In the controlled experiment, 224 kg N/ha gave optimum level of 3.61 percent leaf-N for fruiting trees (Table 3). As these trees were only a year and a half old when the N fertilizer application was begun, N levels higher that 224 kg per hectare gave erratic results. There was an obvious overdose symptom of leaf burning and defoliation. The field plots receiving 224 kg N per hectare had an annual average leaf-N of 2.53 percent (June 1977-May 1978) (Table 8).

In the pot experiment, the mean leaf-N for the deblossomed trees receiving 224 kg N per hectare was 4.35 percent as opposed to 3.61 percent for the fruiting trees. In a study on the partition of assimilates and production of dry matter (13, 14) it was found that a leaf index of 2.3 and a mean solar radiation of 402 cal $cm^{-2}day^{-1}$ had a net dry matter production by fruitless trees during a rainy season to be equivalent to $1.36 \times 10^4$ kg $ha^{-1}$ $annum^{-1}$, a conversion of 0.4 percent of the total incoming short wave radiation for a 5-year old tree. The same report confirmed that the fruits were responsible for about a third of their own dry weight gain. After the initial rapid expansion, coffee fruits represent 20 - 30 percent of the total photosynthetic surface on

bearing trees (14). Although the berries remain at pin-head stage for six-seven weeks with little increment in dry weight, the first 26 weeks of fruit development is considered to be a period of rapid fruit weight increase (48). As the coffee beans act as an extremely powerful dry matter sink, the trees provide dry matter for the powerful seed sink at an early stage of fruit development leading to rapid fruit expansion. Hence, the demand for high amounts of nutrients at this time is unquestionable.

It is generally understood that if a high nitrogen concentration in coffee leaves is due to excessive absorption of the available forms of this element it will lead to an accelerated vegetative growth of the trees (43). This condition is also true in most other crop plants. The highest level of nitrogen (448 kg N per hectare) applied in the first week of March has no significant influence on flowering date when compared to the 224 kg N hectare. The 1978 flowering date was on March 12 where more than 75 percent had anthesis on this date.

The concentration of available form of nitrogen in the soil during the dry weather is low, particularly near the soil surface (6, 51). There might be an upward movement of nitrate-N from the subsoil, but the insufficiency of moisture during the dry months limits its availability to the plant. Shortly after the onset of the rains in March the coffee trees absorb this nitrogen or the nitrogen supplied as fertilizer, rapidly, with a sharp rise in nitrogen content of the leaves. It is also with the onset of rain

or shortly thereafter, that microbial activity begins and operates at a negative balance in the nitrate production. Hence, the March application of nitrogen is justifiable under this condition.

As the rate of uptake of N is according to demand, the greatest uptake is when the tree is growing fast. The rate of uptake of nitrogen and other nutrients is highly significant for a heavily fruiting tree (14). Hence, it is important to keep the tree continuously supplied with nitrogen during the long, rainy season.

Relation of Leaf Nitrogen to Yield

In the wet season the coffee leaf achieves its full size in 6 weeks (37). When leaf and berry sampling was started in June 1977, the third leaf sampled, although young, had reached its full size. Leaves sampled between November and February had not changed much in size as growth was minimum during this period. The dry matter and nutrients are diverted to the fruits, particularly at fruit maturity, leaving very little for growth. Nitrate uptake may be negative after fruit ripening (17). It had been reported that leaf-N near flowering has been well correlated with the yield of the same year (22). But, the lack of response of coffee yield to the levels of N applied in this investigation makes it difficult to make that kind of correlation. In addition, the 1977 leaf sampling was started in June 1977, which does not cover the whole growth period. However, the observation of successive differences of leaf-N mean in the treated plots versus the control in March and April confirms

previous findings that leaf-N near flowering could be correlated to yield of that year (22). Leaf-N can be correlated to next year's yield only indirectly by its influence on starch level.

Coffee yield is a function of a number of environmental factors apart from genetic components. Factors affecting the initiation and growth of flower buds, flower opening and fruit set are important to consider. Fruit load in the previous year and moisture level in both previous and current seasons are some of the major factors in the production of new branches and leaves that will bear and support the current crop (22). The importance of moisture in relation to the utilization of nitrogen was stressed in this study. However, other climatic factors such as light and temperature also play an important role in the level of N nutrient used in coffee.

Nitrogen concentration of the berries was at a high level when young but this decreased with fruit ripening. The lack of sensitivity in berry nitrogen concentration to N fertilizer shows that berries are not good specimens for determining the critical level of this element. It will be more useful in computing the nutrient removed from the soil during its development if the final (ripe cherry) dry weight can be determined.

# SUMMARY AND CONCLUSION

The third or fourth leaf pair from the apex of a lateral primary branch appears to be the most sensitive specimen in the determination of nitrogen concentration in coffee plants. The nitrogen concentration of coffee berry is not influenced by the level of nitrogen concentration of the soil. Hence, coffee berry is found to be a poor specimen in the determination of critical level of nitrogen in coffee.

The choice of the level of N fertilizer and the time of application should be targeted at: (a) stimulating vegetative growth and thus the leaf area of the tree which in turn will result in higher yields, enhancing the maturity of a heavy crop if natural soil N supply is inadequate and (b) preventing the depletion and abscission of the older leaves, which have valuable reserves of other nutrients, and area of photosynthetic unit to supply the increasing dry matter needed by the developing crop.

In earlier work, a significant increase in coffee yield was found in Kona only when a high rate of N (ca. 400 kg $ha^{-1}$) was supplied in frequent application. This increase in yield was achieved when potassium at high rate was applied in two split applications during the growing season. The 450 kg N $ha^{-1}$, the highest rate in this study is high enough to increase yield. But, if this amount is split into four applications during the fruiting season, it might give a better response. Starting application in

mid-February and programming at equal intervals of application between February and October will give a better result than a single application of a high dose in the beginning of the rainy season. Starting from late February through harvest season is a period of high demand of nutrients in the coffee tree. Shoot and root growth resume in late February or early March depending on the onset of the wet season. Anthesis occurs sometime in March. After anthesis active fruit growth starts in April. The vegetative and fruit growth continue through September to October. The withdrawal of nitrogen, other major nutrients, and food is accelerated during this period. To insure enough reserve food for next year's crop and to minimize nitrogen and other nutrient withdrawal from the leaves, the following N application times are suggested. If first application starts in the second half of February, the remaining three applications can be scheduled for the first week of June, mid-August and in the first half of October. Two of these applications should be accompanied by a recommended dose of P and K. Both should be included in the first application with N. Potassium should be at higher dose (ca. 400 kg $K_2O$/ha) since coffee pulp takes high amount of K.

It seems that the occasional irregularity of flowering in Kona is more likely due to the inconsistency of dry and wet periods even within a month than a N fertilizer effect. Moisture regulation, if it can be achieved, seems to be the solution in

timing the crop cycle. Since moisture plays a vital role and insures increased efficiency of the applied fertilizer it will be much better to irrigate the trees after anthesis whenever necessary. However, irrigation from December to February should be avoided to allow moisture stress in the trees to induce uniform flowering.

# APPENDIX

The following conversion factors were used to convert the U.S. units to the metric units. To convert Column A to Column B, multiply by factor:

| Column A | Multiply by | = | Column B |
|---|---|---|---|
| Acre (A) | 0.405 | | hectare (ha) |
| Square foot ($ft^2$) | 0.093 | | square meter ($m^2$) |
| Foot (ft) | 0.305 | | meter (m) |
| Foot (ft) | 30.48 | | centimeter (cm) |
| Inch (in) | 2.54 | | centimeter (cm) |
| Hundred weight (cwt) | 0.454 | | quintal (q) |
| Pound (lb) | 0.454 | | kilograms (kg) |
| Lb/A | 1.12 | | kg/ha |
| Cwt/A | 1.12 | | q/ha |

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